AD-A050 296 STANFORD UNIV CALIF EDWARD L GINZTON LAB F/G 20/3
PROPERTIES OF NEW SUPERCONDUCTING MATERIALS.(U)
DEC 77 T H GEBALLE AFOSR-73-2435
UNCLASSIFIED GL-2760 AFOSR-TR-78-0112 NL

END
DATE FILMED
3-78
DDC

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFOSR-TR-78-0112	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): PROPERTIES OF NEW SUPERCONDUCTING MATERIALS	5. TYPE OF REPORT & PERIOD COVERED: Final Research Report
6. PERFORMING ORG. REPORT NUMBER: ~~G. L. No. 2760~~ G.L.-2760	
7. AUTHOR(s): Theodore H. Geballe	8. CONTRACT OR GRANT NUMBER(s): AFOSR-73-2435
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Stanford University, Department of Applied Physics, Stanford, California	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 2306 C1, 61102 F
11. CONTROLLING OFFICE NAME AND ADDRESS: Directorate of Electronic and Solid State Sciences, Air Force Office of Scientific Research/NE, Bolling AFB Building 410, Washington, D.C. 20332	12. REPORT DATE: Dec 77
	13. NUMBER OF PAGES: ~~18~~ 21 pp.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Superconductivity
High transition temperatures
Vapor deposition
Electron-phonon interaction
Metastable phases
layered-metal dichalcogenides
intercalation compounds
two-dimensional superconducting
anisotropic transport

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A large number of new and unusual superconductors have been discovered and their superconducting response to changes effected chemically, crystallographically, and physically has been studied. In this way, the interactions giving rise to superconductivity were examined. The effort has been concentrated in two major areas. First, the two-dimensionality of layered transition metal dichalcogenides has allowed for a closer comparison between theory and experiment. Second, studying the instabilities of the high transition temperature phases has led to a greater understanding of the role of crystal structure and stoichiometry.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

409 640

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. For example, a new method of stabilizing films of Nb_3Ge with superconducting transitions above 22K enabled the homogeneous stoichiometric composition to be reached by epitaxial growth on polycrystalline substrates. Thus, new approaches have been uncovered for synthesizing compounds with even higher superconducting transition temperatures.

AFOSR-TR- 78-0112

FINAL REPORT

FOR

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

AIR FORCE SYSTEMS COMMAND, U.S. AIR FORCE

Grant No. AFOSR-73-2435

PROPERTIES OF NEW SUPERCONDUCTING MATERIALS

by

Professor T. H. Geballe
Principal Investigator

Department of Applied Physics
Stanford University
Stanford, California 94305

G. L. Report No. 2760

December 1977

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFSC)
NOTICE OF TRANSMITTAL TO DDC
This technical report has been reviewed and is approved for public release IAW AFR 190-12 (7b).
Distribution is unlimited.
A. D. BLOSE
Technical Information Officer

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PROPERTIES OF NEW SUPERCONDUCTING MATERIALS		5. TYPE OF REPORT & PERIOD COVERED Final Research Report 6. PERFORMING ORG. REPORT NUMBER G. L. No. 2760
7. AUTHOR(s) Theodore H. Geballe		8. CONTRACT OR GRANT NUMBER(s) AFOSR-73-2435
9. PERFORMING ORGANIZATION NAME AND ADDRESS Stanford University Department of Applied Physics Stanford, California		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2306-C1 61102-F
11. CONTROLLING OFFICE NAME AND ADDRESS Directorate of Electronic and Solid State Sciences Air Force Office of Scientific Research/NE Bolling AFB Building 410, Washington, D.C. 20332		12. REPORT DATE December 1977 13. NUMBER OF PAGES 18
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Superconductivity
High transition temperatures
Vapor deposition
Electron-phonon interaction
Metastable phases
layered-metal dichalcogenides
intercalation compounds
two-dimensional superconducting
anisotropic transport

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A large number of new and unusual superconductors have been discovered and their superconducting response to changes effected chemically, crystallographically, and physically has been studied. In this way, the interactions giving rise to superconductivity were examined. The effort has been concentrated in two major areas. First, the two-dimensionality of layered transition metal dichalcogenides has allowed for a closer comparison between theory and experiment. Second, studying the instabilities of the high transition temperature phases has led to a greater understanding of the role of crystal structure and stoichiometry.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. For example, a new method of stabilizing films of Nb_3Ge with superconducting transitions above 22K enabled the homogeneous stoichiometric composition to be reached by epitaxial growth on polycrystalline substrates. Thus, new approaches have been uncovered for synthesizing compounds with even higher superconducting transition temperatures.

During the period of the grant and its predecessor an entirely new class of superconductors - the intercalated layered transition metal dichalcogenides - was discovered and investigated. More than 75 new superconducting crystals of this class have been synthesized in collaboration with the industry-supported group of F. R. Gamble and associates. This probably represents most of the new superconductors discovered during the past 10 years.

The distinguishing feature of these intercalated superconductors is that there are easily identifiable dichalcogenide layers in which the conduction takes place. These superconductors are the most anisotropic compounds known. The conductivity in the approximately 6 angstrom thick dichalcogenide layer was found to be that of a typical metallic alloy. The rest of the unit cell of the crystal is formed by an organic insulating layer which, in the case of octadecylalamine is 50 angstroms thick. Electrical anisotropies of greater than 10^5 have been found at room temperature for some of the more perfect crystals. The anisotropic Ginzburg-Landau parameters in 20 different single crystal superconductors were investigated using newly developed heat capacity methods as well as electrically. The coherence length in $TaS_{1.6}Se_{1.4}(C_6H_5N)$ was found to be only 4.5 angstroms in the direction perpendicular to the layers (vs 220 angstroms parallel to the layers). The perpendicular distance is less than the interlayer separation of the conducting dichalcogenide layers demonstrating that the magnetic field can pass through the superconductor without inducing large diamagnetic screening currents. As a consequence, the upper critical field (measured parallel to the surface) was found to increase at the record rate of > 140,000 gauss per degree as the sample was cooled below its transition.

Using new electrolytic methods of intercalations, the stoichiometric compound $-TaS_2(H_2N\text{-}CH_2\text{-}CH_2\text{-}NH_2)_{1/4}$ was formed upon intercalation of

monocrystalline 4H(b)-TaS_2 (a polymorph of TaS_2 with four layers per unit cell), with ethylenediamine. In contrast to 4H(b)-TaS_2 (T_c <0.5K), the intercalated compounds were found by heat capacity measurements (1) to undergo a bulk superconducting transition near 3 K, (2) to have a marked increase in its electronic density of states and (3) to show the intriguing possibility of being a superconductor with no energy gap. The transition temperature was also raised to about 3 K in 4Hb-TaS_2 by intercalation of hydrogen apparently because of hydrogen's role in suppressing the charge density waves. The latter are instabilities driven by the Fermi-surface. Thermal and electrical properties in the hexagonal polymorphs of $NbSe_2$, TaS_2, $TaSe_2$, and the mixed trigonal and hexagonal polymorphs of TaS_2 and $TaSe_2$ were measured and interpreted in terms of a model in which only a small fraction of the Fermi surface participates in the formation of the charge density wave. A systematic study of the optical properties in a series of crystals in the 1T($Ti_{1-x}Ta_xS_2$) system has suggested why these compounds behave electrically as semiconductors on the Ta-rich side rather than as the superconductors one would expect. Analysis of their Drude-like optical behavior shows that scattering times become remarkably short for the tantulum rich compounds ($x \geq 0.6$), so short in fact that the Boltzmann transport equation no longer applies. An unexpected quadratic dependence of resistivity upon temperature was found over a wide range in TiS_2 suggesting electron-hole scattering as the mechanism.

B. W. Roberts in "Survey of Superconductive Materials and Critical Evaluation of Selected Properties", has tabulated in Table III, a copy of which is appended, the properties of superconducting materials with organic and related constituents. References 1128 and 1192 in particular refer to research discussed above. This important work has resulted in widespread national and international recognition and has directly stimulated new

research in other laboratories. A special conference was sponsored by the ONR,"Physics and Chemistry of Layered Compounds", Monterey, California, August 1972, a Gordon Research Conference has been held "Chemistry and Phyiscs of Solids", Holderness School, Plymouth, N.H., August 1975, and an international conference, "Layered Semiconductors and Metals", a Satellite Conference of I.C.P.S., has been held in Bari, Italy, September 1976. An active group has developed at the University of Illinois under F. C. Brown, W. M. McMillan, and others. Work in the high magnetic field properties and superconductive fluctuations at high temperatures was undertaken by M. R. Beasley, A. H. Luther and R. A. Klemm at Harvard and has been continued by D. Prober at Yale. Important charge density wave instabilities were discovered at Bell Laboratories by F. J. DiSalvo, J. R. Wilson and S. Mahajan. More indirectly linked research on the mechanism of the intercalation reaction has resulted in promising new battery electrodes by workers at Exxon and Bell.

During the latter part of the grant an improved method of growing high temperature A-15 compounds was developed using the method of electron beam codeposition. Elements were evaporated from individually controlled electron beam sources exploiting a method of fast feedback developed in this laboratory. The phase diagram of Nb_3Ge below 1000 K was investigated and showed that the Ge-rich boundary extends beyond the 20-22 at % previously established and exhibits an unusual temperature dependence when trace gases such as O_2 and $C\ell_2$ are present in the evaporator at partial pressures of 10^{-5} - 10^{-6} torr. A careful investigation of Nb_3Ge showed no evidence for a low-temperature martensitic transformation such as that found in Nb_3Sn . A potentially very powerful new method, "polycrystalline" epitaxy, which in some sense is equivalent to molecular beam epitaxy, was developed for synthesizing metastable compounds. Using this method the Ge-rich phase

boundary of Nb_3Ge was extended from the thermodynamic limit of 19 atomic percent to 26 at %. Either Nb_3Ir or Nb_3Rh pre-evaporated as a polycrystalline substrate was found to be effective since both have suitable lattice constants. The resulting Nb_3Ge films were found to have superconducting transition temperatures which maximize, at the stoichiometric composition, with temperatures in excess of 22 K. Another consequence of this electron beam technology was the development of a method to produce oxide tunnel junctions of Nb_3Sn in which parameters such as composition could be varied systematically for the first time.

New approaches have been opened for the synthesis of stoichiometric compositions of other A-15 compounds for which the thermodynamic limit of the B element is less than 25% such as Nb_3Al and Nb_3Ga. By analogy with what has been found for Nb_3Ge the superconducting transitions should be above the present values of 18.8 K and 20.7 K respectively. The possibility of making Nb_3Si stable in the A-15 phase by epitaxial means has also been opened, and here the transition temperature is expected to exceed the highest present day value of 23 K.

There were other significant developments in this 5 year period including a new method of introducing hydrogen into palladium electrolytically from methanol at - 80 C which resulted in stoichiometric PdH with $T_c = 9.1$ K. This method has been adopted by other research groups both in the US and abroad. A relationship was established between hydrogen concentration and the resistivity maxima observed at temperatures above T_c due to clustering of the hydrogen. The prototype of a possible new class of metallic compounds was found in collaboration with C. W. Chu, visiting from Cleveland State, and A. P. Rusakov, a Russian visitor at Stanford under an exchange program.

CuCl was found to transform into a highly-conducting state over a relatively narrow pressure range above 40 Kbar. The new phase occurred as an intermediate between the low pressure (cubic) and high pressure (rock-salt) phases both of which are insulators. Further research has been carried out by both Dr. C. W. Chu, now at University of Houston, and Dr. Rusakov in Moscow.

TABLE 3. Properties of Superconductive Materials with Organic and Related Constituents

NOTE: "HF" Signifies high-magnetic-field data in Table 5.

Material	T_c(K)	H_o (oersted)	Crystal Structure	T_n(K)	Refs.
Al(and tetracyanoquino-dimethan)	2.7-5.24 1.9-3.7(annealed)				▽1078
Be(with KCl layers; deposit 4.2K)	10.6-6.5				▽1028
Be(with zinc-etioporphyrin; deposit 4.2K; ≥ 500 Å)	10.2				▽1028
$CaH_{18}N_6$				1.9	010
$H_{12}LiN_4$				1.9	010
In (with Anthraquinone, 5000Å)	3.4-4.6				▽1076 ▽1528
$MoS_2Ba_{0.2}(NH_3)_x$	5.7		HEX		1918
$MoS_2Ca_{0.2}(NH_3)_x$	3.6		HEX		1918
$MoS_2Sr_{0.01-1}(NH_3)_{0.01-1.62}$	5.2-4.9				1918
$MoS_2Yb_{0.1}(NH_3)_{0.16}$	2.4		HEX		1918
$MoSe_2Sr_{0.2}(NH_3)_x$	5.0		HEX		1918
NS	0.26				1986 1975#
NbS_2 (Ammonia)	2.0		HEX		1192
NbS_2 (Aniline)$_?$	4.0		HEX		1192
NbS_2 (S-collidine)$_{0.17}$	3.5		HEX		1192
NbS_2 (pyridine)$_{0.5}$	4.0		HEX		1192 1027
NbS_2 (tributylphosphine)$_{0.125}$	3.5		HEX		1192
Nb_3Sn (with CO_2, CO, CH_3, N_2, O_2, ammonium, boron tricloride, ethane, hydrogen sulfide, nitrogen oxide, propane)		HF			1169 1168 ▽1437
$PdTe_2$ (pyridine)$_{0.5}$	1.65				1027
$S_{2-1}Se_{0-1}Ta$ (pyridine)$_{0.5}$	0.8-3.3-1.6		HEX		1910
S SeTa (pyridine)	1.5	HF	HEX		1262
S_2Ta (2-aminopyridine)$_{0.53}$	3.25		HEX		1128
S_2Ta (4-aminopyridine)$_{0.51}$	3.4		HEX		1128
S_2Ta (ammonia)	4.2		HEX		1192
S_2Ta (ammonium acetate)	2.0		HEX		1192
S_2Ta (ammonium hydroxide)	3.3		HEX		1192
S_2Ta (amylamine)	2.2				1192
S_2Ta (aniline)	3.1		HEX		1192
S_2Ta (aniline)$_{0.75}$	3.1		HEX		1192

TABLE 3 (Cont'd). Properties of Superconductive Materials with Organic and Related Constituents

NOTE: "HF" Signifies high-magnetic-field data in Table 5.

Material	T_c(K)	H_o (oersted)	Crystal Structure	T_n(K)	Refs.
S_2Ta (barium hydrate)$_{0.15}$	3.74	150	HEX		1845
S_2Ta (butylamine)	2.5		HEX		1192
S_2Ta (butyramide)	3.1		HEX		1192
S_2Ta (calcium$_{(0.3)}$hydrate)	3.47				1770 1845
S_2Ta (calcium$_{(0.15)}$hydrate)	3.47	130	HEX		1845
S_2Ta (cesium$_{(0.3)}$hydrate)	2.75, 2.80	110	HEX		1845 1770
S_2Ta (cesium hydroxide)	3.8		HEX		1192
S_2Ta (s-collidine)$_{0.17}$	2.0, 1.95		HEX		1192 1871
S_2Ta (2,6-diaminopyridine)$_{0.53}$	3.50		HEX		1128
S_2Ta (2-dimethylaminopyridine)$_{0.32}$	3.15		HEX		1128
S_2Ta (4-dimethylaminopyridine)$_{0.34}$	2.30		HEX		1128
S_2Ta (N,N-dimethylaniline)	4.3		HEX		1192
S_2Ta (2,6-dimethlpyridine)$_{0.20}$	2.15		HEX		1128
S_2Ta (4,4'-dipyridyl)	2.5		HEX		1192
S_2Ta (ethylamine)	3.3		HEX		1192
S_2Ta (2-ethylpyridine)$_{0.29}$	3.0		HEX		1128
S_2Ta (3-ethylpyridine)$_{0.29}$	4.50		HEX		1128
S_2Ta (4-ethylpyridine)$_{0.33}$	2.95		HEX		1128
S_2Ta (hexanamide)	3.1		HEX		1192
S_2Ta (hydrazine)	4.7		HEX		1192
S_2Ta (hydrogen)$_{0-0.87}$	0.8-4.2-<0.5				1871
S_2Ta (2-isopropylpyridine)$_{0.25}$	3.80		HEX		1128
S_2Ta (4-isopropylpyridine)$_{0.28}$	2.82		HEX		1128
S_2Ta (isoquinoline)	2.5		HEX		1192
S_2Ta (lithium hydrate)$_{0.3}$	3.83	170	HEX		1845
S_2Ta (lithium hydroxide)	4.5		HEX		1192
S_2Ta (methylamine)	4.2		HEX		1192
S_2Ta (2-methylpyridine)$_{0.34}$	2.95		HEX		1128
S_2Ta (3-methylpyridine)$_{0.33}$	2.95		HEX		1128
S_2Ta (4-methylpyridine)$_{0.33}$	2.70		HEX		1128
S_2Ta (octadecylamine)	3.0		HEX		1192

TABLE 3 (Cont'd). *Properties of Superconductive Materials with Organic and Related Constituents*

NOTE: "HF" Signifies high-magnetic-field data in Table 5.

Material	T_c(K)	H_o (oersted)	Crystal Structure	T_n(K)	Refs.
S_2Ta (pentadecylamine)	2.8		HEX		1192
S_2Ta (p-phenylenediamine)	3.3		HEX		1192
S_2Ta (p-phenylenediamine)$_{0.25}$	2.9		HEX		1192
S_2Ta (2-phenylpyridine)$_{0.255}$	3.15		HEX		1128
S_2Ta (4-phenylpyridine)$_{0.26}$	1.6		HEX		1128
S_2Ta (picoline)$_{0.34}$	2.70		HEX		1871
S_2Ta (potassium formate)	4.7		HEX		1192
S_2Ta (potassium$_{(0.3)}$hydrate)	5.25	230	HEX		1845 1770
S_2Ta (potassium hydroxide)	5.3		HEX		1192
S_2Ta (propylamine)	3.0		HEX		1192
S_2Ta (4-propylpyridine)$_{0.25}$	2.75		HEX		1128
S_2Ta (2-propylpyridine)$_{0.245}$	2.85		HEX		1128
S_2Ta (pyridine)$_{0.5}$	3.5	HF	HEX		1192 1027
S_2Ta (pyridine)$_{0.5}$	3.55		HEX		1128 1871
S_2Ta (pyridine)$_{0.5}$	3.25	HF			1262 1430
S_2Ta (pyridine-N-oxide)	2.5		HEX		1192
S_2Ta (pyridinium chloride)	3.1		HEX		1192
S_2Ta (quinoline)	2.8		HEX		1192
S_2Ta (rubidium$_{(0.3)}$hydrate)	4.40	210	HEX		1845 1770
S_2Ta (rubidium hydroxide)	4.3		HEX		1192
S_2Ta (septadecylamine)	2.7		HEX		1192
S_2Ta (sodium$_{(0.3)}$hydrate)	5.41	250	HEX		1845 1770
S_2Ta (sodium hydroxide)	4.8		HEX		1192
S_2Ta (stearamide)	3.1, 3.0		HEX		1192
S_2Ta (strontium$_{(0.2)}$ ammonium)	2.8		HEX		1918
S_2Ta (strontium$_{(0.15)}$ hydrate)	4.03	190	HEX		1845
S_2Ta (tetradecylamine)	2.4		HEX		1192
S_2Ta (N,N,N',N'-tetramethyl-p-phenylenediamine)	2.9		HEX		1192
S_2Ta (thiobenzamide)	3.3		HEX		1192
S_2Ta (tributylamine)	3.0		HEX		1192
S_2Ta (tributylphosphine)$_{0.125}$	2.0		HEX		1192
S_2Ta (tridecylamine)	2.5		HEX		1192

TABLE 3 (Cont'd). Properties of Superconductive Materials with Organic and Related Constituents

NOTE: "HF" Signifies high-magnetic-field data in Table 5.

Material	T_c(K)	H_o (oersted)	Crystal Structure	T_n(K)	Refs.
S_2Ta (2,4,6-trimethyl-pyridine)$_{0.165}$	1.95		HEX		1128
S_2Ta (triton B)	5.0		HEX		1192
S_2Ta (valeramide)	2.9		HEX		1192
$S_2Ta_{0.8}W_{0.2}$(s-collidine)$_{0.17}$	2.0		HEX		1192
$S_2Ta_{0.3}W_{0.7}$(s-collidine)$_{0.17}$				~0.4	1192
S_2Ti (ammonia)			HEX	0.3	1192
S_2Ti (aniline)			HEX	0.3	1192
S_2Ti (s-collidine)$_{0.17}$			HEX	0.3	1192
S_2Ti (pyridine)$_{0.5}$			HEX	0.3	1192
S_2Ti (tributylphosphine)$_{0.125}$			HEX	0.3	1192
S_2W (strontium$_{(0.2)}$ ammonium)	3.5		HEX		1918
S_2W (ytterbium$_{(0.4)}$ ammonium)	2.2		HEX		1918
S_2Zr (ammonia)			HEX	0.3	1192
Se_2Ta (pyridine)$_{0.5}$	1.5		HEX		1027
Se_2W (strontium$_{(0.2)}$ ammonium)	~1.4		HEX		1918
V (co-deposited with organic compounds, 50-200Å)	T_c'(+~0.1, -~0.1)				V1802

PUBLICATIONS DURING GRANT PERIOD

1. "Structure and Superconducting Properties of Intercalated 4Hb-TaS_2 ," by S. F. Meyer, T. H. Geballe, and J. V. Acrivos, Bull. Am. Phys. Soc. 18 384 (March 1973).

2. "Superconductivity in Palladium Hydride," by J. M. E. Harper, R. Hammond, and T. H. Geballe, Bull. Am. Phys. Soc. 18, 326 (March 1973).

3. "Superconducvitiy in LiPdGe Compounds," by T. H. Geballe, J. M. Voorhoeve, and G. W. Hull, Jr., Bull. Am. Phys. Soc. 18, 384 (March 1973).

4. "Superconducting Properties of Alkali and Alkaline Earth Intercalates of Transition Metal Dichalcogenides," by J. V. Acrivos and S. F. Meyer, Bull. Am. Phys. Soc. 18, 385 (March 1973).

5. "Heat Capacity Measurements of Layered Superconducting Compounds, by R. E. Schwall, G. R. Stewart, R. E. Howard, and J. F. Revelli, Bull. Am. Phys. Soc. 18, 385 (March 1973).

6. "Optical Properties of Layered Compounds, Intercalated with Organic Molecules," by J. A. Benda, J. F. Revelli, and W. A. Phillips, Bull. Am. Phys. Soc. 18, 386 (March 1973).

7. "Infrared Reflectance Spectra of Layered Group IV and Group VI Transition Metal Dichalcogenides," by G. Lucovsky, R. M. White, J. A. Benda, and J. F. Revelli, Phys. Rev. B 7, 3859 (April 1973).

8. "Optical and Resistivity Studies of Intercalated Layered Compounds," by J. A. Bends, R. E. Howard, and W. A. Phillips, J. Phys. Chem. Solids 35, 937 (1974).

9. "Pressure Dependence of the Metal-Insulator Transition in Tetrathiofulvalinium Tetracyanoquinodimethane," by C. W. Chu, J. M. E. Harper, T. H. Geballe, and R. L. Greene, Phys. Rev. Letters 31, 1491 (December 1973).

10. "Optical and Heat Capacity Studies of the Solid Solutions $Ti_xTa_{1-x}S_2$," by J. A. Benda, C. N. King, K. R. Pisharody, and W. A. Phillips, Internal Memorandum (January 1974). Presented at 13th International Conference on Low Temperature Physics, LT-13, (August 1972). Published in LT-13, Vol. 4.

11. "Optical Reflectivity in A15 Compounds," by J. A. Benda, T. H. Geballe, and J. H. Wernick, Phys. Letters 46A, 389 (January 1974).

12. "Pressure Enhanced Superconductivity in $NbSe_2$," by T. F. Smith R. N. Shelton and R. E. Schwall, J. Phys. F: Metal Phys., 4, 2009 (November 1974).

13. "On Superconducting Metal-Ammonia Complexes," by J. V. Acrivos, S.F. Meyer, and R. H. Geballe, in Electrons in Fluids, edited by J. Jortner and N. R. Kestner (Springer-Verlag, New York, 1973), p. 341.

14. "Properties of Intercalated 2H-$NbSe_2$, 4Hb-TaS_2 , and 1T-TaS_2 ," by S. F. Meyer, R. E. Howard, G. R. Stewart, J. V. Acrivos, and T. H. Geballe, J. Chem. Phys. 62, 4411 (1975).

15. "Properties of H_xTaS_2 : Correlation between the Superconducting T_c and an Electronic Instability in Layer Compounds," by D. W. Murphy, F. J. Di Salvo, G. W. Hull, Jr., J. V. Waszczak, S. F. Meyer, G. R. Stewart, S. Early, J. V. Acrivos, and T. H. Geballe, J. Chem. Phys. 62, 967 (1975).

16. "Superconducting Materials Up to Now and Into the Future," by T. H. Geballe and J. K. Hulm, presented at the 1974 Applied Superconductivity Conference; IEEE Trans. Mag. MAG-11, 119 (1975).

17. "The Low Temperature Heat Capacity of Amorphous Germanium," by C. N. King, W. A. Phillips, and J. P. DeNeufville, Phys. Rev. Letters 32, 538 (1974).

18. "Preparation and Properties of 1T-$TaSe_2$," by F. J. Di Salvo, B. G. Bagley, R. G. Maines, J. V. Waszczak, and R. E. Schwall, Solid State Commun. 14, 497 (1974).

19. "Optical, Electrical-Transport, and Heat-Capacity Studies of the Solid Solutions $Ti_xTa_{1-x}S_2$, $Zr_xTa_{1-x}S_2$, and $Ti_xNb_{1-x}Se_2$," by J. A. Benda, Phys. Rev. B 10, 1409 (1974).

20. "Effect of Hydrogen Concentration on Superconductivity and Clustering in Palladium Hydride," by J. M. E. Harper, Phys. Letters 47A, 69 (1974).

21. "Optical, Electrical-Transport, and Heat Capacity Studies of the Solid Solutions $Ti_xTa_{1-x}S_2$, $Zr_xTa_{1-x}S_2$, and $Ti_xNb_{1-x}Se_2$," by J. A. Benda, Bull. Am. Phys. Soc. 19, 339 (1974).

22. "Heat Capacities of Au-Al_2O_3 Thin Films," G. R. Stewart and B. Abeles, Bull. Am. Phys. Soc. 19, 347 (1974).

23. "Rate of Intercalation of Transition Element Dichalcogenides," by J. R. Salem and J. V. Acrivos, presented at Symposium of Colloid and Surface Chemistry; Bull. Am. Chem. Soc.

24. "Electronic Structure of MnBi ," by W. Stutius, R. M. White, T. Chen, and G. R. Stewart, presented at 20th Annual Conference on Magnetism and Magnetic Materials, San Francisco, December 1974; in Proceedings of 20th Annual Conference on Magnetism and Magnetic Materials.

25. "Insertion Compounds of 2H-$TaS_2 \cdot NH_3$," by S. F. Meyer, J. V. Acrivos, and T. H. Geballe, Proc. Nat. Acad. Sci. USA 72, 464 (1975).

26. "Properties of New Superconducting Materials," Interim Scientific Report (October 1974), G. L. Report 2365.

27. "High Pressure Metallic Phase in Cuprous Chloride Single Crystals," by C. W. Chu, T. H. Geballe, S. Early, R. E. Schwall, and A. Rusakov, J. Phys. C 8, L241 (1975).

28. "Thermal Properties of Boron Phases," by N. Bilir, W. A. Phillips, and T. H. Geballe, in Proceedings of 14th International Conference on Low Temperature Physics, LT-14, Helsinki, August 1975.

29. "Automated Small Sample Calorimeter," by R. E. Schwall, R. E. Howard, and G. R. Stewart, Rev. Sci. Instrum. 46, 1054 (1975).

30. "Pressure Enhanced Superconductivity in $NbSe_2$," by T. F. Smith, P. N. Shelton, and R. E. Schwall, J. Phys. F 4, 2009 (1974).

31. "Electron Beam Evaporation Synthesis of A15 Superconducting Compounds: Accomplishments and Prospects," by R. H. Hammond IEEE Trans. Mag. MAG-11, 201 (1975).

32. "Critical Current Density in Superconducting Niobium Films," by R. P. Huebener, R. T. Kampwirth, R. L. Martin, T. W. Barbee, Jr., and R. B. Zubeck, IEEE Trans. Mag. MAG-11, 344 (1975).

33. "Low Temperature Specific Heat of Polysulfur Nitride $(SN)_x$," by J. M. E. Harper, P. M. Grant, B. G. Street, and R. L. Greene, Bull. Am. Phys. Soc. 20, 360 (1975).

34. "Low Temperature Thermal and Electrical Properties of Chemical-Vapor-Deposited Nb_3Ge ," by J. M. E. Harper, T. H. Geballe, L. R. Newkirk, and F. A. Valencia, J. Less-Common Metals 43, 5 (1975).

35. "Heat Capacity of 2H-$NbSe_2$ at the Charge Density Wave Transition," by J. M. E. Harper, T. H. Geballe, and F. J. Di Salvo, Phys. Letters 54A, 27 (1975).

36. "Size Effects in the Heat Capacity of Small Platinum Particles Imbedded in Silica," by G. R. Stewart, Phys. Rev. B 15, 1143 (1977).

37. "Detection of Nuclear Quadrupole Resonances via Induced Longitudinal Magnetization," by T. Jach, Appl. Phys. Lett. 28, 49 (1976).

38. "Superconductivity and Range of Existence of the A15 Phase in the Nb-Ge Systems," by A. Hallak, R. H. Hammond, R. B. Zubeck, and T. H. Geballe, Bull. Am. Phys. Soc. 21, 340 (1976).

39. "Low Temperature Specific Heat of Layered Compounds," by R. E. Schwall G. R. Stewart, and T. H. Geballe, J. Low Temp. Phys. 22, 557 (1976).

40. "Properties of New Superconducting Materials," Interim Scientific Report for the period 1 October 1974 - 30 September 1975 (November 1975), G. L. Report 2495.

41. "Phase Diagram of Electron Beam Codeposited Nb_3Ge: The Influence of Oxygen," by A. B. Hallak, R. H. Hammond, T. H. Geballe and R. B. Zubeck, IEEE Trans. Mag. MAG-13, 311 (1977).

42. "Synthesis and Stability of Nb_3Ge Made by Electron-Beam Codeposition," by A. B. Hallak, R. H. Hammond, and T. H. Geballe Appl. Phys. Lett. 29, 314 (1976).

43. "Optical and Electrical Studies of Ti and Ta-dichalcogenides: Plasmons," by W. Y. Liang, G. Lucovsky, R. M. White, W. Stutius and K. R. Pisharody, Philosophical Magazine, 33 493-403 (1976).

44. "Magnetic and Electric Properties of MnSb ," by T. Chen, J. W. Allen, and G. R. Stewart, in Proceedings of 21st Annual Conference on Magnetics and Magnetic Material, Philadelphia, December 1975.

45. "The Elastic Behavior of 2H-$TaSe_2$," by M. Barmatz, L. R. Testardi, F. J. Di Salvo, and J. M. E. Harper, Phys. Rev. B 13, 4637 (1976).

46. "Reflectivity Studies of Ti- and Ta-Dichalcogenides: Phonons," by G. Lucovsky, W. Y. Liang, R. M. White, and K. R. Pisharody, Solid State Commun. 19, 303 (1976).

47. "Superconductive Tunneling into Niobium-Tin Thin Films," by D. F. Moore J. M. Rowell, and M. R. Beasley, Solid State Commun. 20, 305 (1976).

48. "Properties of New Superconducting Materials," Annual Research Progress Report, (November, G. L. Report 2635.

49. "Superconducting Materials," by T. H. Geballe, presented at Distinguished Lecture Series III, University of New Mexico, March 1976 (Proceedings in press).

50. "Superconductivity Defects and Stoichiometry in A15 Materials," by R. C. Dynes, J. M. Poate, L. R. Testardi, A. R. Storm, and R. H. Hammond, IEEE Trans. Mag. MAG-13, 640 (1977).

51. "Electron-Beam Fabrication of A15 Superconducting Materials," by R. H. Hammond and R. B. Zubeck, presented at American Society for Metals Conference on Manufacture of Superconducting Materials, Port Chester, New York, November 1976, in press.

52. "Thermal Properties of Layered Transition Metal Dichalcogenides at Charge Density Wave Transitions," by J. M. E. Harper, T. H. Geballe and F. J. Di Salvo, Phys. Rev. B15, 2943 (1977).

53. "Epitaxial Growth of High-T_c Superconducting Nb_3Ge on Nb_3Ir," by A. H. Dayem, T. H. Geballe, R. B. Zubeck, A. B. Hallak and G. W. Hull, Jr., Appl. Phys. Lett. 30, 541 (1977).

54. "Epitaxial Growth of Nb_3Ge on Nb_3Ir and Nb_3Rh," by A. H. Dayem T. H. Geballe, R. B. Zubeck, A. B. Hallak and G. W. Hull, in press.

PERSONS WORKING ON GRANT DURING GRANT PERIOD

Benda, J. A. — Ph.D. awarded June 1973

(Thesis title: Optical and Heat Capacity Studies of Some Transition Metal Compounds)

Bilir, N. — Ph.D. awarded May 1974

(Thesis title: Low Temperature Heat Capacities of Open-Structured Crystals)

Early, S. R. — Ph.D. expected June 1978

Feldman, R. — Ph.D. expected June 1980

Hallak, A. B. — Ph.D. awarded June 1976

(Thesis title: Superconductivity and Range of Existence of the A15 Phase in the Niobium-Germanium System)

Hammond, R. H. — Senior Research Associate

Harper, J. M. E. — Ph.D. awarded October 1975

(Thesis title: Thermal Properties of Metals with Low Temperature Structural Instabilities)

Ierley, G. — Received Masters September 1977

Jach, T. J. — Ph.D. awarded August 1975

(Thesis title: Observation of Nuclear Quadrupole Resonance with Superconducting Magnetometers)

Kimhi, D.* — Ph.D. expected June 1979

Kwo, J.* — Ph.D. expected June 1979

McDavid, G. T. — Received Masters April 1974

Meyer, S. F. — Ph.D. awarded January 1974

(Thesis title: The Effect of Intercalate and Layer Properties on Superconducting Transition Metal Dichalcogenides)

Moore, D. F.* — Ph.D. expected April 1978

O'Connor, M. C. — Ph.D. expected June 1978

Pisharody, R. — Visiting Research Associate

Phillips, A. W. — Visiting Assistant Professor

Salem, J. R. — Research Associate

Schwall, R. E. Ph.D. awarded June 1973

(Thesis title: Low Temperature Properties of Layered Transition Metal Dichalcogenide Compounds)

Stewart, G. R. Ph.D. awarded October 1975

(Thesis title: I. Size Effects in the Heat Capacity of Small Metal Particles II. Heat Capacity of the Systems MnBe and MnSb)

Rowell, J. M. Consulting Professor

Younge, R. C. Graduate Research Assistant

Zubeck, R. B. Ph.D. awarded September 1973

(Thesis title: Effects of Deformation on Mixed State Heat Capacity)

*Primary support has not been from AFOSR grant.

Presentations and Visits During Grant Period

T. H. Geballe

10/21/74 - SLAC (seminar: "High Temperature Superconductors")

11/13/74 - UC Berkeley (seminar: "High Temperature Superconductors and Their Applications")

11/18/74 - Bell Labs (seminar: "Applied Superconductivity: Status and Prospects")

4/4/75 - CERL, Leatherhead, Surrey, England (visited J. Sutton and discussed use of high-T_c superconductors in applied technology)

5/2/75 - Cambridge Univ., England (seminar: "Charge Density Waves in Superconductors and Transition Metal Dichalcogenides")

5/9/75 - Brown, Bovari Co., Baden, Switzerland (visited A. Menth, discussed superconducting technology)

5/14/75 - Institute fur Experimentalle Kernphysik, Karlsruhe, Germany (visited W. Heinz, discussed synthesis of superconducting compounds using dual beam and sputtering techniques; also, new developments of Karlsruhe in ion implantation)

5/15/75 - Siemans, Stuttgard, Germany (visited M. Wilhelm, discussed synthesis of V_3Ga)

5/29/75 - A.E.R.E., Harwell, England (visited R. Bett, J. Charlesworth, J. Lee, P. Madsen; discussed Nb_3Sn irradiation damage and manufactur of multifilamentary Nb_3Sn)

6/4/75 - Imperial College, England (seminar: "Instabilities in Superconductors")

7/28-8/1/75 - Gordon Conference (chaired session on instabilities in layered dichalcogenides)

12/3/75 - UC Berkeley (seminar: "Superconducting Power Transmission Lines")

2/19/76 - UC Santa Cruz (seminar: "Use of Helium and Applied Superconductivity")

2/24/76 - Bell Laboratories (seminar: "The Superconducting Power Transmission Line")

3/4/76 - "Distinguished Lecture Series, U New Mexico (Superconductivity: Materials for Energy Use")

8/17-20/76 - 1976 Applied Superconductivity Conference (Conference Chairman

8/14-15/77 International Conference on Physics of Transition Metals, Toronto, Canada

11/14/77 General Motors Research Laboratories, Warren, Michigan (seminar: "Superconductivity in Transition Metals")

J. M. E. Harper

4/7-11/75 IBM, Yorktown Heights, New York

Exxon Research and Engineering Co., Linden, New Jersey

Bell Laboratories, Murray Hill, New Jersey

(seminar: Thermal Properties of Metals with Low Temperature Structural Instabilities)

T. J. Jach IBM, Yorktown Heights, New York

Bell Laboratories, Murray Hill, New Jersey

(seminar: Observation of Nuclear Quadrupole Resonance with Superconducting Magnetometers)